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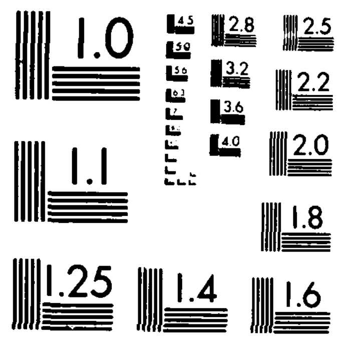

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The purpose of this project ~~is to~~ construct, and study, a laser trap for neutral atoms, initially potassium (K). At low densities, such a trap could be used to address a number of fundamental questions, e.g. the interaction of an individual atom with an electromagnetic field, collision dynamics and recombination. ~~We have studied~~ the feasibility and limitations of a purely laser trap concept, a "corner cube trap", for trapping neutral K atoms. The confinement of the atoms in the two dimensions perpendicular to the laser is provided in the cavity of a newly constructed high power alexandrite laser operating in

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20. the CW TEM^*_{01} mode ("doughnut mode") tuned slightly to the blue side of the resonance line of the K atom. By reflecting the ~~TEM^*_{01}~~ laser back on itself with two mirrors, one "caps" the ends of the cylindrical trap, resulting in a slightly weaker end plug. This trap concept employs not laser cooling, but rather counterstreaming ^{4}He atoms which are cooled to ~1.5 K, to drastically cool the K atoms to ~~thermal~~ energies well below the trap depth (expected to be ~10 K). We have also examined various loss mechanism for the trapped atoms. In particular, K atoms are lost to the trap if they are multiphoton ionized, if they are heated by absorption and emission of many photons ~~("recoil" or~~ "diffusional" heating), if they simply have much higher energy than the vast majority of other atoms at 1.5 K, or if they recombine with He to form KHe (or KHe_2, etc.). Results from these investigations are discussed, suggesting crude lifetimes for trapped atoms of the order of 1 second. Emphasis in the initial studies discussed herein is in development and characterization of the new alexandrite laser, demonstration of the trap at low densities, and determination of the spatial and velocity distribution of atoms in the trap.

IATRAP-86-1

Office of Naval Research

Annual Summary

for

15 November 1985 through 14 November 1986

for

Contract N00014-83-K-0646

Project Task Area Number RR-011-03-03

A Laser Trap for Neutral Atoms

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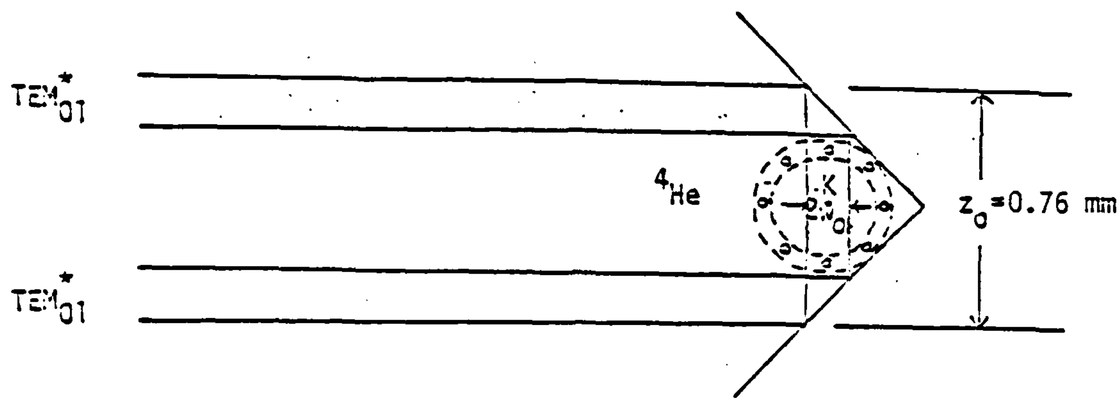
<u>Recent Progress on Designing and Constructing a Laser Trap for Neutral Atoms</u>

Recently there has been a great deal of interest in trapping neutral atoms for the reasons given in our recent work (e.g. [STW 84]) and also many more reasons in other contributions to the volume in which it appears. Purely magnetic traps are quite attractive and are being pursued successfully at NBS (Gaithersburg) [PRO 85], but are orders of magnitude weaker than the laser trap discussed here. Two laser traps [DAL 83, DAL 84] are also quite promising, but we feel it is better to start with the simpler one-laser trap, as in our theoretical work [YAN 86] and the experiments of Chu *et al*. [CHU 86].

Our initial studies of neutral traps involved the laser-magnet hybrid trap [STW 84]. Because of the complex Zeeman structure of the atoms in the magnet field of the hybrid trap, however, a number of issues (diffusional heating, optical pumping, multiphoton ionization, etc.) become correspondingly complex. Hence we have decided to attempt initially to implement a purely laser trap, similar to those proposed by Ashkin [ASH 78, ASH 79, ASH 80, GOR 80] and then reconsider the laser-magnet trap at a later date. The primary differences in our laser trap concept (Figure 1) is that our "corner cube trap" (a) is <u>within</u> a TEM_{01}^{*} laser cavity; and (b) employs not laser cooling, but rather counterstreaming ^4He atoms (which do not interact with the trapping laser) which have been cooled to $\lesssim 1.5$ K to drastically cool K atoms (vaporized above room temperature) to thermal energies well below our estimated 8.6K trap depth. In contrast, the recent work of Chu *et al*. [CHU 86] involves an extra-cavity TEM_{00} laser beam of lower power and low trap depth (~5 mK) with "optical molasses" cooling to ~240 μK.

In particular, if the laser frequency is slightly to the blue of the atomic resonance frequency, the atom will experience a relatively strong "transverse dipole" force pushing it into the central region of weaker light intensity. This force has been dramatically demonstrated in the Na atom focusing

Corner Cube Trap



K: K atoms injected into the paper
^{4}He: Ring of ^{4}He beams out of the paper

Figure 1. Proposed Corner Cube Trap for Neutral Potassium Atoms. The laser beam is actually strongly focused at the beam waist w_0, so the trap has something like an hourglass shape.

experiments of Bjorkholm and coworkers [BJO 78, BJO 80, PEA 80]. If one employs a TEM_{01}^{*} ("doughnut mode") laser beam, one confines the atom in two dimensions (x and y, $\perp$ to the laser). By reflecting the TEM_{01}^{*} laser beam back on itself with two mirrors, one "caps" the ends of the cylindrical trap, albeit with a slightly weaker end plug (the laser intensity is down by a factor of 2 at the Rayleigh range and the trap depth down by $\sqrt{2}$). We have used spatial filtering to reliably and stabily operate our new cw alexandrite laser as well as argon and krypton ion lasers in the TEM_{01}^{*} mode.

We have selected K atoms since a suitable high power tunable CW laser, the Allied alexandrite laser, is now available and since the multiphoton ionization rate is particularly low for K. The Allied alexandrite laser is not yet commercially available, but Allied has built us a second CW alexandrite laser well in advance of commercialization. It has been operational in Iowa since February 1986. The initial CW alexandrite laser achieved 60 watts CW output; with a high reflector in place of the output coupler, 3000 watts intracavity should be obtainable. The lengthening of the cavity, and introduction of a tuning element and other optical surfaces will reduce this, but with this laser, the achievement of intracavity power densities exceeding 10^8 W/cm^2 (hence trap depths approaching 10 K) is a realistic near term goal.

We have chosen ^{4}He for cooling initially because temperatures $\lesssim 1.5$ K can be readily achieved with high cooling power by pumping on liquid helium and because ^{4}He is inexpensive. Future designs might employ ^{3}He (which is quite expensive) or even spin-polarized hydrogen ($H\downarrow$) (which would add considerable complexity), but we shall not consider them here.

The parameters we have chosen for our initial trap experiments are given in Table I. Note that the AC Stark width greatly exceeds the ordinary (Doppler) width ($\lesssim 10^3$ MHz) of the K atomic line. Note also the various loss rates in Table I. In particular, K atoms can be lost to the trap if they are multi-

Table I. Initial experimental parameters for the Iowa TEM^*_{01} Intracavity Laser Corner Cube Trap for ^{4}He-Cooled ^{39}K Atoms.

Maximum intensity of TEM^*_{01} 765.3 nm laser (at $w_0/\sqrt{2}$)	1.52×10^8 W/cm^2 (standing wave)
Trap depth (maximum) at beam waist $w_0/\sqrt{2}$	8.6 K
Trap depth (minimum) at Rayleigh range z_0	5 K
Laser detuning to the blue of $^2S_{1/2}$ - $^2P_{3/2}$	5.23×10^5 MHz
AC Stark shift to the red (at $w_0/\sqrt{2}$)	3.08×10^4 MHz
AC Stark full width at half maximum (at $w_0/\sqrt{2}$)	9.13×10^5MHz
Beam waist w_0	14 μm
Rayleigh range z_0	0.76 mm
Multiphoton ionization rate	1.2 sec^{-1}
Diffusional heating rate	4.3×10^3 K/sec
Thermal escape rate	~10 sec^{-1}
Recombination rate (if appropriate)	≤1 sec^{-1}

photon ionized, if they are heated by absorption and emission of many photons ("recoil" or "diffusional" heating), if they simply have a much higher kinetic energy than the vast majority of other atoms at a temperature of 1.5 K, or if they form KHe (or KHe_2, etc.).

The choice of detuning is made through consideration of three important factors: well depth, multiphoton ionization rate and diffusional heating. As detuning increases, both well depth and diffusional heating decrease, but multiphoton ionization rate increases. We have chosen $\Delta = 2\Delta_0$, where Δ_0 is the "optimal" detuning [GOR 80] for a given laser intensity, to satisfy the conditions: (a) the maximum and the minimum well depths are well over the expected temperature (1-1.5 K) of the trapped atoms; (b) the ^{4}He collisional cooling rate will significantly exceed the diffusional heating rate; and (c) the multiphoton ionization rate remains in the neighborhood of 1 sec^{-1}.

The multiphoton ionization rate is uncertain because of the uncertainty in the cross section and because the rate varies drastically with kinetic energy of the K atom (hotter atoms sample higher laser intensities). Nevertheless, rates in the range 0.1-10 sec^{-1} are expected.

Diffusional heating is the most serious objection to Ashkin's original traps. However, by introducing a vast excess of cold ^{4}He (e.g. $n_K \simeq 10^6$ atoms/cm^3; $n_{^4He} \simeq 10^{18}$ atoms/cm^3 (which is roughly half the vapor pressure of liquid helium at 1.5 K)), each K atom undergoes a very large number of collisions (~10^8/sec). This should provide more than adequate cooling, despite the 4300 K/sec which must be removed. Note that the "high" density of ^{4}He is still small enough that the pressure broadening of the K resonance line should be negligible ($\lesssim$100 MHz).

The thermal escape rate (assuming the diffusional heating problem is eliminated by ^{4}He cooling) will be comparable (perhaps somewhat larger) than the multiphoton ionization rate. In both cases, of course, atoms at the "hot" end

of the kinetic energy distribution will be lost and it is not yet clear to us how fast the "hole" at the top of the thermal distribution will be refilled by collisions of initially colder atoms. In addition, the time for the K atoms to diffuse through the cold ^{4}He to the laser trap "walls" will be much slower than that given by collisionless motion.

A final loss mechanism is the formation of KHe. This species has, to our knowledge, never been observed, but theoretical calculations of the interaction potential between K and He do exist. Presumably the best of these is that of Pascale [PAS 83, PAS 85]. Using his potential with a well depth of 1.9 cm^{-1} (~2.7 K) and an equilibrium distance of 13.2 a_0, one calculates three levels bound by less than 0.25 cm^{-1} (v = 0, J = 0 and 1 and v = 1, J = 0) and two quasibound levels (v = 0, J = 2 and v = 1, J = 1). This corresponds to a vibrational-rotational partition function of ~13 in the limit that T is large compared to the binding energy. The corresponding equilibrium constant (for number densities in units of atoms/cm^3) is then at 1.5 K

$$K = (n_{KHe})/(n_K n_{He}) \simeq 6 \times 10^{-21}.$$

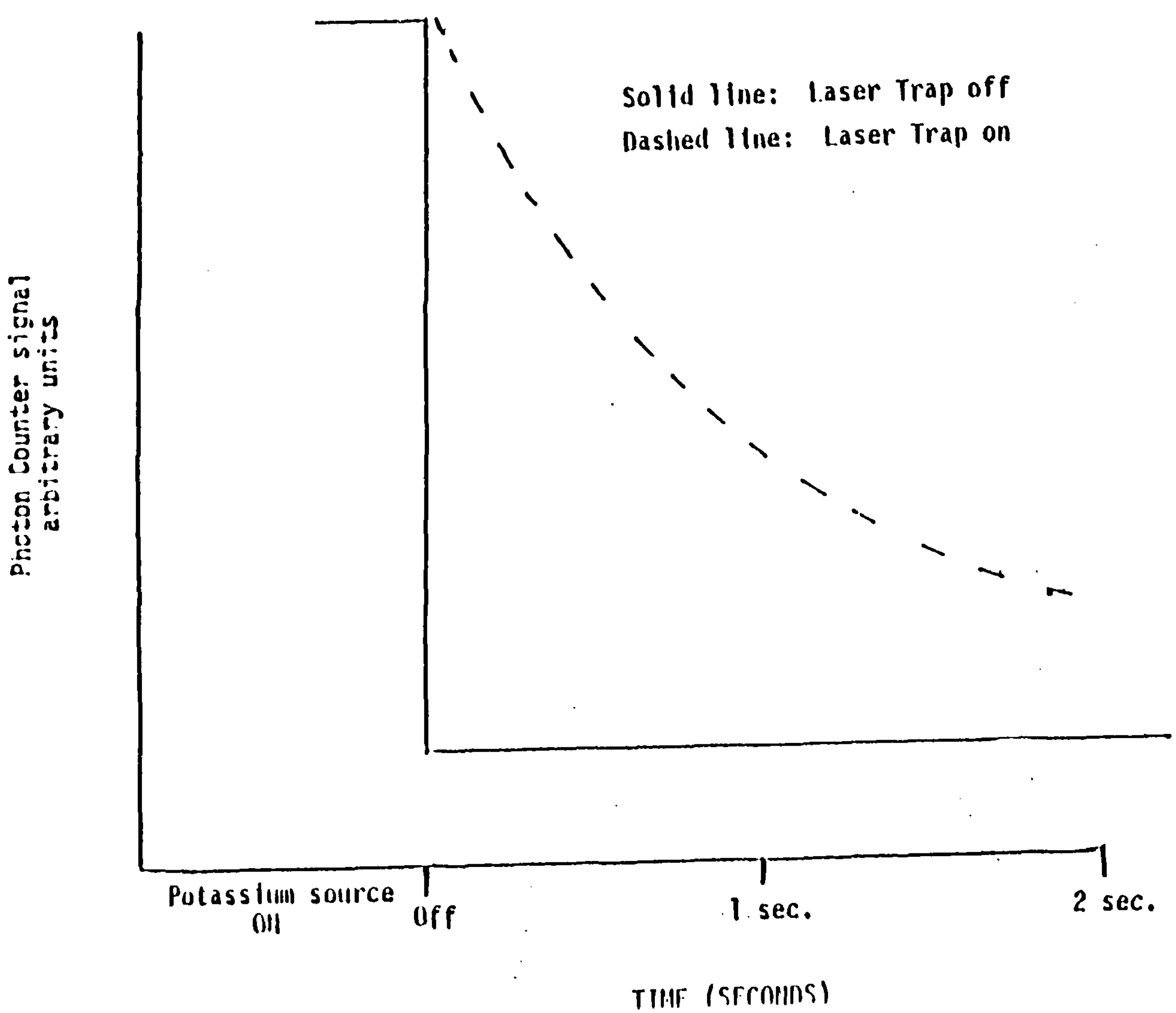
For $n_K = 10^6$ and $n_{He} = 10^{18}$ as above, $n_{KHe} = 6 \times 10^3$ or 0.6% of the K is tied up as KHe as equilibrium. If the well depth of the KHe potential was significantly greater, this percentage might be much higher; if the well depth were less, there might be fewer or even no bound states. Even if KHe is a concern, its interaction with the laser field remains to be examined (photodissociation; dipole force; multiphoton ionization; etc.). Use of ^{3}He would reduce the KHe problem; lowering T (perhaps 1 K can be achieved by carefully considering the cooling by pumping of liquid helium) would increase the recombination. The rate (as opposed to the equilibrium constant) is completely unknown for K + He + He → KHe + He; a reasonable value of 10^{-36} cm^6/$atoms^2$ (as for H + H + He → H_2 + He at 4 K) gives ~1 sec^{-1} for recombination.

Assuming the fastest loss rates are ~1 sec^{-1}, we could simply study the

decay rate of K concentration with time as the K source (filling the trap) was turned off (see Figure 2). The detection is straightforward using either of the 5p $\rightarrow$ 4s fluorescences (at ~404.5 nm) (or possibly the $4p_{1/2} \rightarrow 4s$ fluorescence at 769.9 nm). Variation in the laser intensity and ^{4}He density and detection of the KHe molecule could be used to attempt to sort out the competing trap losses. Room temperature experiments were carried out this past year to establish and optimize the high sensitivity of this detection method.

Finally, a major manuscript detailing our trap has appeared in Phys. Rev. A. [YAN 86]. The major goal in the coming year is to successfully operate the alexandrite laser with cryogenic intracavity mirrors and then to trap K atoms, cooled with counterstreaming He, between these mirrors in our TEM_{01}^* trap.

Figure 2. Decay Profile of 4045Å Fluorescence in a 1 Second Trap



References

ASH 78 A. Ashkin, Phys. Rev. Letters 40, 721 (1978).

ASH 79 A. Ashkin and J. P. Gordon, Opt. Lett. 4, 161 (1979).

ASH 80 A. Ashkin, Science 210, 1081 (1980).

BJO 78 J. E. Bjorkholm, R. R. Freeman, A. Ashkin and D. B. Pearson, Phys. Rev. Lett. 41, 1361 (1978).

BJO 80 J. E. Bjorkholm, R. R. Freeman, A. Ashkin and D. B. Pearson, Optics Letters 5, 111 (1980).

CHU 86 S. Chu, J. E. Bjorkholm, A. Ashkin and A. Cable, Phys. Rev. Lett. 57, 314 (1986).

DAL 83 J. Dalibard, S. Reynaud and C. Cohen-Tannoudji, Opt. Commun. 47, 395 (1983).

DAL 84 J. Dalibard, S. Reynaud and C. Cohen-Tannoudji, J. Phys. B 17, 4577 (1984).

GOR 80 J. P. Gordon and A. Ashkin, Phys. Rev. A 21, 1606 (1980).

PAS 83 J. Pascale, Phys. Rev. A 28, 632 (1983).

PAS 85 J. Pascale, private communication, 1985.

PEA 80 D. B. Pearson, R. R. Freeman, J. E. Bjorkholm and A. Ashkin, Appl. Phys. Lett. 36, 99 (1980).

PRO 85 J. Prodan, A. Migdall, W. D. Phillips, I. So, H. Metcalf and J. Dalibard, Phys. Rev. Lett. 54, 992 (1985).

STW 84 W. C. Stwalley, Prog. Quant. Electr. 8, 203 (1984).

YAN 86 K. H. Yang, W. C. Stwalley, S. P. Heneghan, J. T. Bahns, K. K. Wang and T. R. Hess, Phys. Rev. A 34, 2962 (1986).

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